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Development of European VVER-440 Fuel Assembly by Framatome

Guy Gentet

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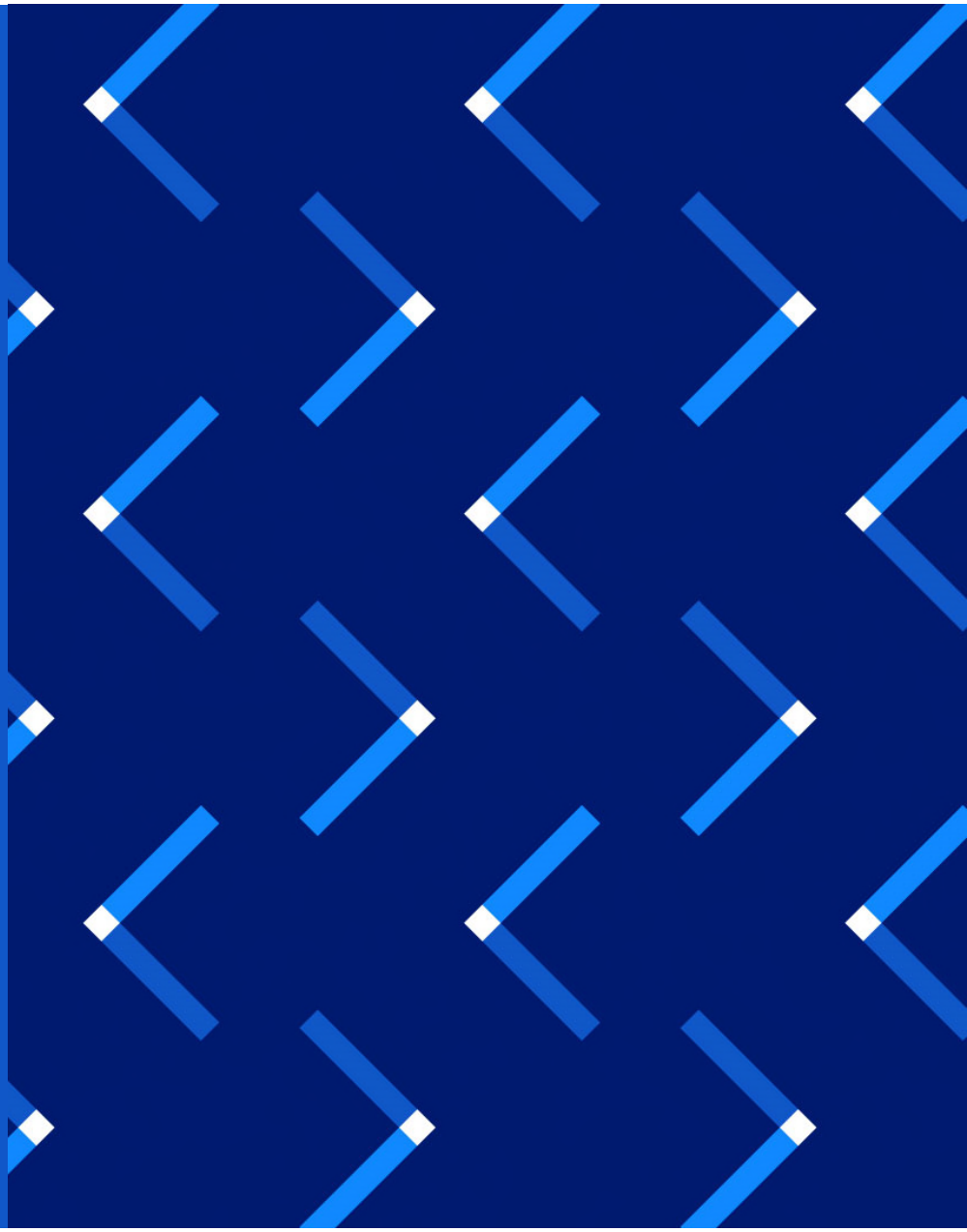


European VVER fuel market
Framatome dual-track approach

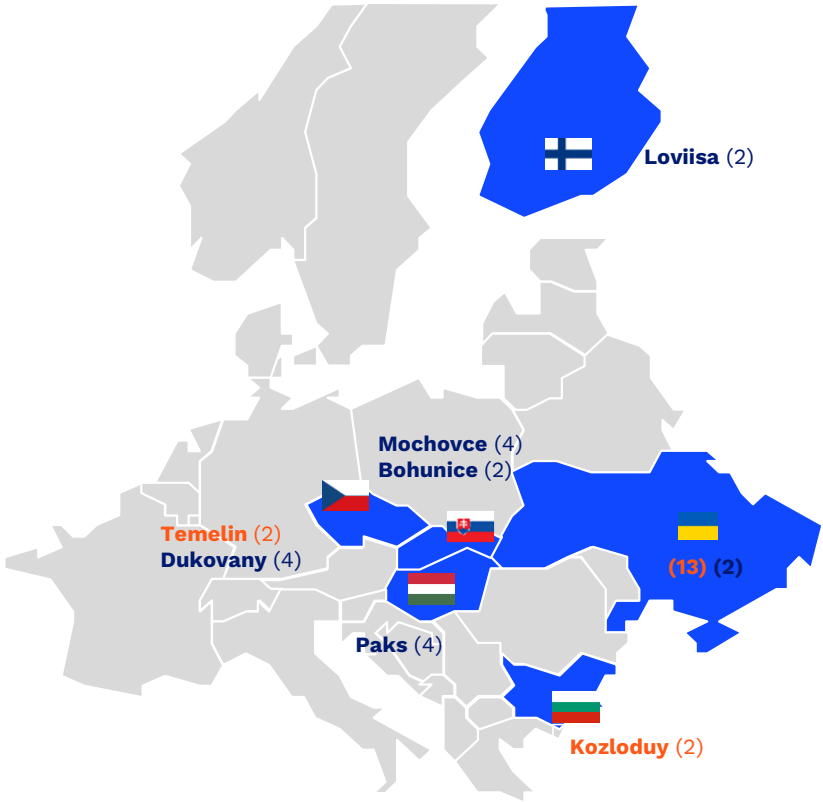
Two parallel approaches:

Proven design immediately available with no licensing uncertainties

Security of supply with the OEM **proven** and **reliable** product

Full-speed development of a new technology to be qualified in reactors:

Diversity of supply with **the only fully European sovereign** solution



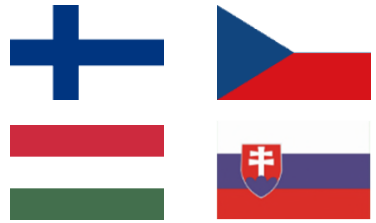
Framatome VVER-440 Development project

Project Objectives

- Develop VVER-440 fixed fuel assembly (fiFA) and follower fuel assembly (foFA) for 4 European utilities (Fortum, ČEZ, Slovenské Elektrárne and MVM Paks)
- Develop a transport container for shipping VVER-440 fiFA and foFA
- Fuel assemblies (fiFA & foFA) and container shall be European sovereign designs
- Lead Fuel Assemblies shall be ready to start irradiation by mid-2029

Approach

- Framatome fuel design activities and testing supporting fuel assembly development is carried out in Germany and France
- External support provided by CEA, Skoda and UJP Praha
- Qualification of the VVER fuel technology will be achieved through a LFA program in Loviisa with 4 annual cycles to provide the relevant technical information demonstrating the ability of the fiFA and foFA designs perform as expected



FoFA fiFA

Framatome received EU funding to develop a 100% sovereign European own-design fuel for VVER-440 reactors

Framatome SAVE project gathers 17 partners from 8 European countries

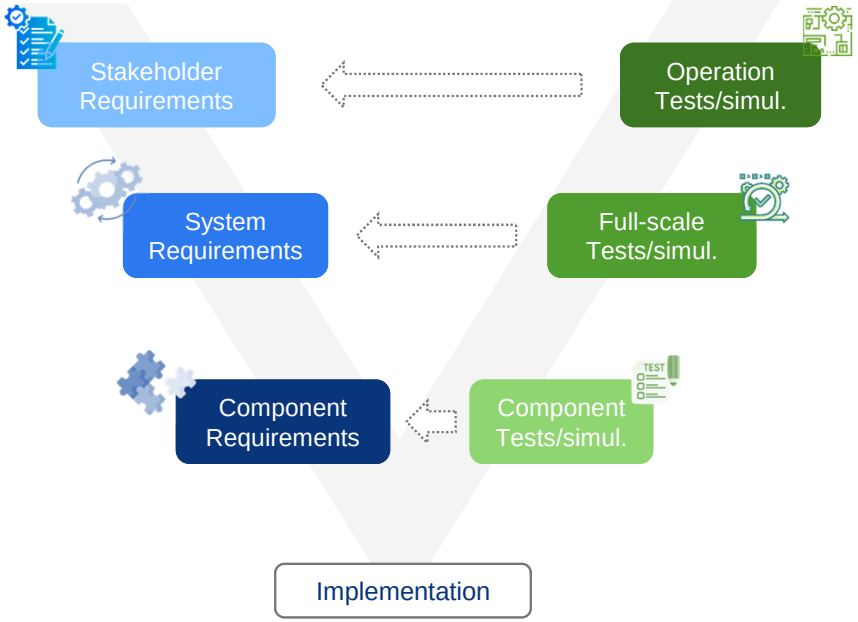
- SAVE: Safe and Alternative VVER European Fuel
- Started in July 2024
- Duration: 48 Months
- Funding from Europe: 10M€
- Consortium leader: framatome
- Main outcomes
  - To validate the performance of VVER-440 fuel assembly supporting European countries through an extensive qualification program
  - To prepare in pile qualification program
  - To create a multi-national network of expertise and knowledge to position a European supplier for future fuel deliveries

FRAMATOME SAS
CEA
Framatome GmbH
STUDSVIK
PAKS
BME
EK
CEZ
UJV-REZ
UJP
SKODA
FORTUM
VTT
SE
VUJE
ENERGORISK
Abilico

VVER-440 Project development process

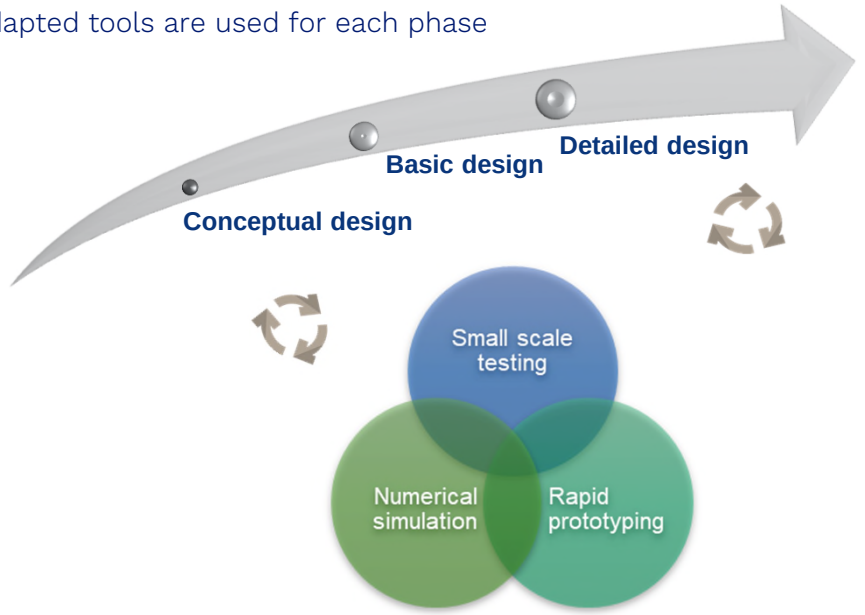
Framatome is relying on robust development processes to secure the technical performances of the new fuel assemblies: **V-model and Design Stages**

The V-model in systems engineering provides a structured approach that ensures every requirement is systematically addressed and verified



Progressive elaboration, starting from broad ideas and moving towards precise, actionable plans

Adapted tools are used for each phase

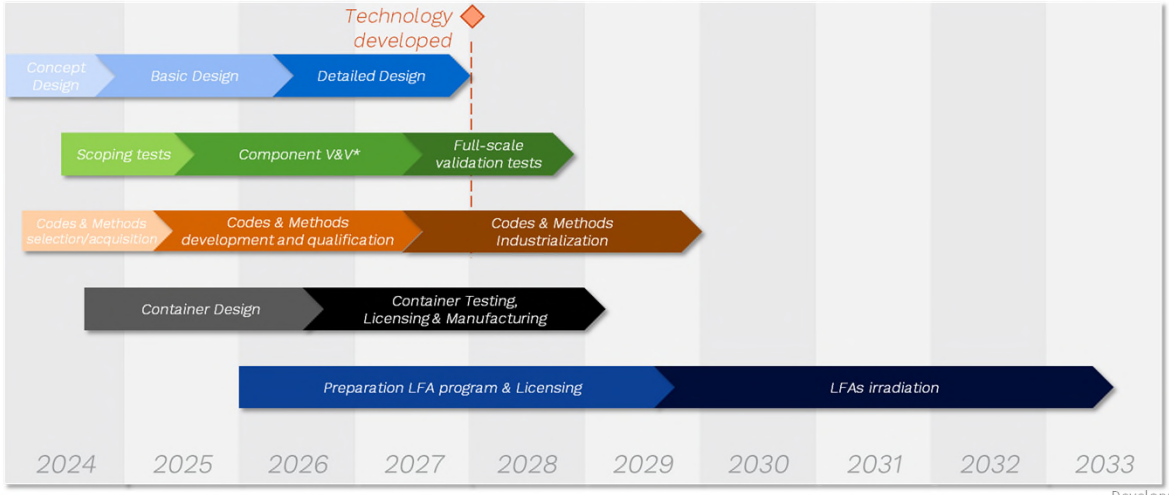


Systems Engineering: Integrating Innovation for Safer, Smarter Fuel Assemblies

VVER-440 Fuel Assembly

Main Characteristics

- 126 fuel rods at Ø 8.9 mm, snapped into bottom nozzle
  - Solid UO_2 pellets, $M5_{Framatome}$ cladding
  - Optional: PROtect EATF*
- Full shroud (Q12) removable together with top nozzle
- 9…11 spacer grids
  - 7 to 9 from Q12, 0 to 2 from A718
- Optional: 3D-print anti-debris filter highly adjustable to customer needs
  - 3D-print from 316L, highly adjustable to customer needs



follower FA fixed FA

*: See presentation "PROtect Cr: The leading E-ATF solution by Framatome"

VVER-440 Verification & Validation (V&V)

Assembly

- Full bundle stiffness test
- Drop test
- Dynamic behavior in accident conditions
- Transport load simulation
- Flow-induced vibration tests (PETER loop)
- Life test (HERMES-P endurance test)
- Mixing and CHF testing (KATHY loop)
- Neutronic calculations

Top Nozzle

- Hold-down capability
- PLC analyses
- Shroud connection load test
- Load tests / simulations

Spacer Grid

- Material qualification
- Rod contact zone and clamping
- Rod fretting resistance
- PLC analyses (and testing)
- Buckling
- Instrum. tube connections

Shroud

- Material qualification
- Nozzle connection tests
- Creep and ballooning FEM
- Mounting functional test

Instrum. Tube

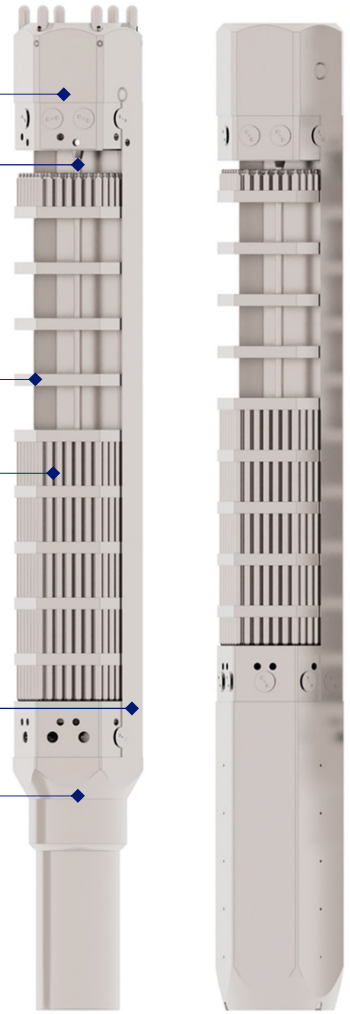
- Material qualification
- Load, strength, buckling
- Insertion check
- Connections load

Fuel Rod

- Material qualification
- Mechanical design justification
- Clamping / extraction

Bottom Nozzle

- PLC analyses (and testing)
- Body and tie plate strength
- Connections loads
- Mounting functional test



V&V plan to secure the development objectives & timeline in compliance with Systems Engineering approach

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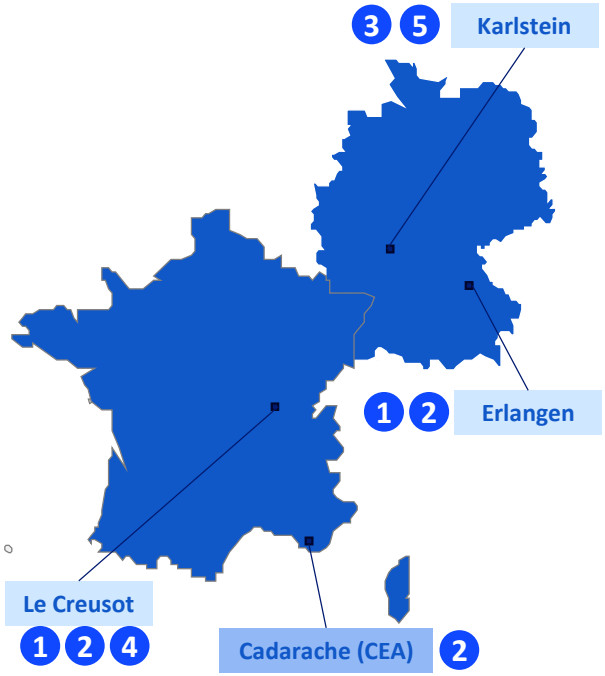
Framatome Prototyping & Test Facilities
Used for VVER-440

- Framatome unique prototyping and testing capacities
  - To get necessary data to build and validate models and calculations
  - To carry out scoping tests to validation tests prior to first introduction in reactor
  - To simulate the behavior of the fuel assemblies in real core conditions or representative core conditions
  - To manufacture early version of components, including reactor grade components for Lead Fuel Assembly programs
- Framatome will also rely on SAVE partners testing capacity
  - Full-size pressure drop tests in Skoda loop
  - Full-size life & wear test in HERMES-P loop at CEA



1. Mechanical tests
2. Hydraulic tests
3. Thermal hydraulic tests
4. Material tests
5. Prototyping

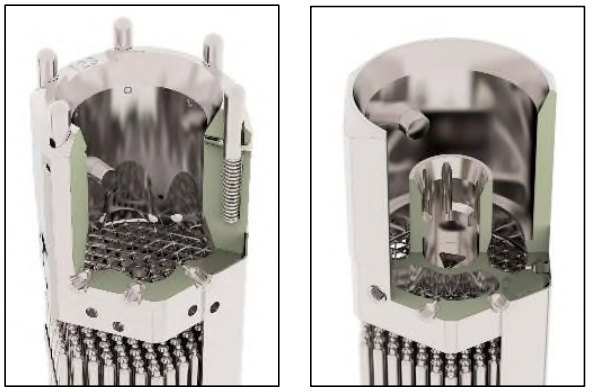
Prototyping and test facilities: extensive capabilities to support development and validate FA designs

VVER-440 Fuel Assembly

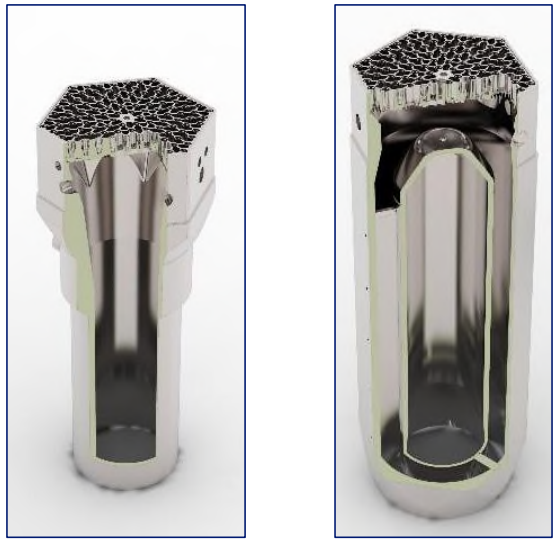
Conceptual Design phase completed

Fuel rod	Fuel Rod cladding and pellet dimensions defined Fuel rod seated and secured in the bottom nozzle
Outer skeleton (shroud)	Closed Shroud for both fixed and follower Fuel Assemblies Removable connection with bottom nozzle
Spacer Grid	Two grid concepts kept for basic design: • Paver: Individual cells stamped and folded from strip welded together • Tri-hexagon: straight-strips welded by laser
Bottom Nozzles	Tie plate combined with 3D printed filter like VVER-1000 solution Manufacturability confirmed through prototypes
Top Nozzles	3D printed upper flow plate Manufacturability confirmed through prototypes

Top Nozzles



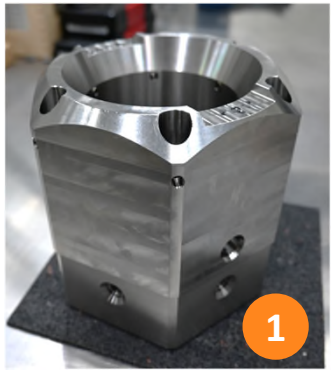
Bottom Nozzles



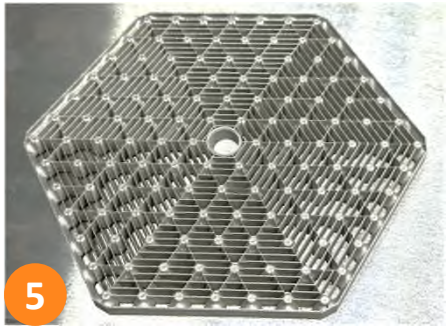
Experience acquired on VVER-1000 allows faster development of the VVER-440 FA designs

VVER-440 Fuel Assembly
Top & bottom nozzles prototyping

- First prototypes of top nozzles and bottom manufactured
  - First prototypes of all 4 nozzles confirmed manufacturability as is
  - Allowed to identify improvements vs manufacturability
  - Supports improvement under implementation in the Basic Design phase
  - Use of 3D-Print components



1. fiFA top nozzle body
2. fiFA bottom nozzle body
3. foFA bottom nozzle body
4. Tie plate
5. 3D-print stopper plate
6. foFA top nozzle body



Procurement of new prototypes underway to support mechanical testing

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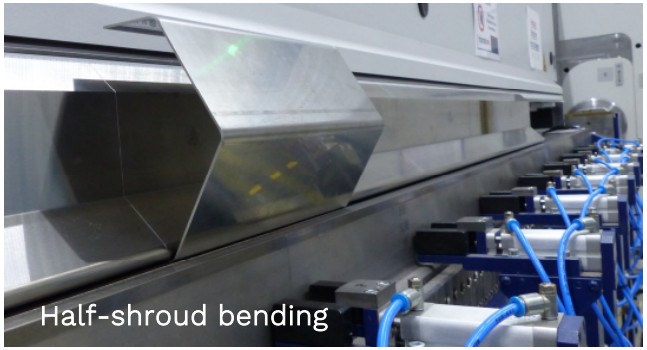
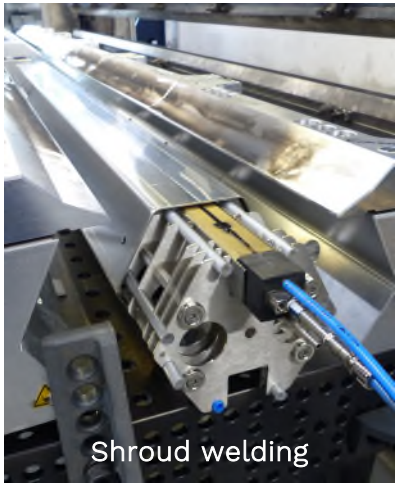
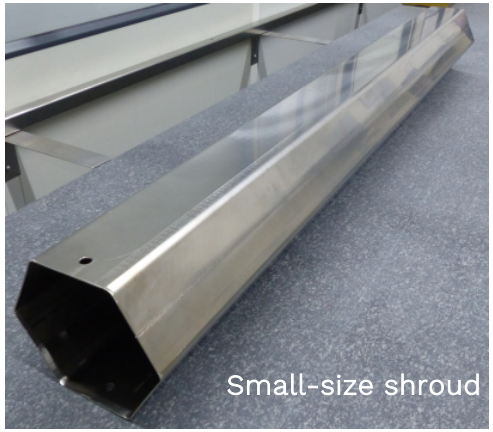
VVER-440 Fuel Assembly
Shrouds manufacturing

- Prototyping of shrouds
  - Production of Zr plates confirmed at Framatome Rugles manufacturing plant
  - First manufacturing tests on half-size shroud successfully completed at Framatome Karlstein facility


Half-shroud bending


Shroud welding


Small-size shroud

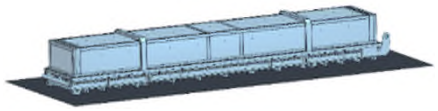
  - Second manufacturing tests campaign underway to manufacture full-size shrouds to confirm manufacturability and provides shrouds to support the first mechanical tests

Development of new manufacturing process is progressing in line with the project schedule

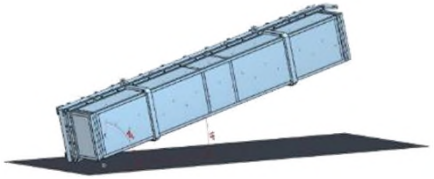
Framatome container for VVER-440

- A dedicated container is being developed to ship Framatome VVER-440 fuel assemblies
- The Framatome VVER-440 container will be a new container
  - Not based on an existing container design
- Completion of the Conceptual Design Phase in July 2025
  - Selection of the design for next development phase
  - Innovative design with 4 fuel assemblies per container (patent application)

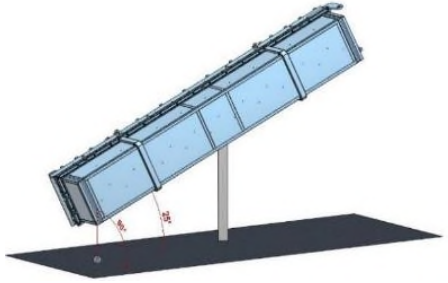
- The container is being developed in France and will be first licensed in France before extension to other countries
- The standard IAEA test program will be carried out to support the licensing of the container



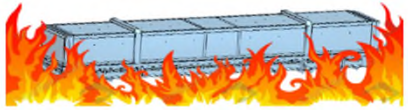
1. Drop of the container from 1.2m height onto the bottom structure



2. Drop of the container from 9m height onto the worst position



3. Drop of the container onto a spike on the side with 15°



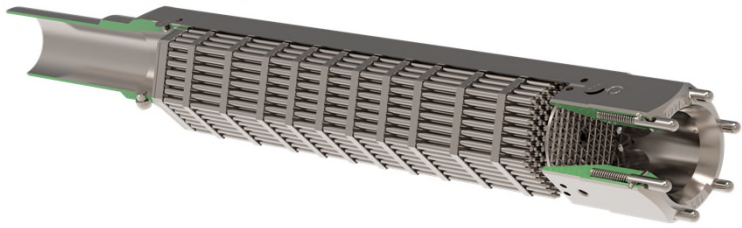
4. Heating test with 800°C for 30 minutes

Summary

Framatome 100% sovereign European VVER fuel design

Framatome has been developing since 2024 a 100% European sovereign VVER-440 fuel assembly and dedicated container

- VVER-440 FA “Basic Design” phase underway since 2025
  - Prototyping of all components underway
- VVER-440 Lead Fuel Assemblies readiness targeted for 2028
  - Final testing campaign to be completed by mid-2028
- VVER-440 Container “Basic Design” phase underway since mid-2025



Fully on track to start the in-core qualification of the Framatome design, a robust and performant technology, via LFAs before the end of this decade

Acknowledgements

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the European Union

The European Union is partly funding the Framatome VVER-440 FA development by SAVE, a new Innovative Action under the Euratom Research and Training Program; Project number: 101114771.

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